Visualizing Pavement Management Data at the Project Level

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 ABSTRACT
As a Pavement Management System increases in maturity, so does the amount of information powering it.   As the level of information grows, efficiently communicating the data becomes difficult. The Washington State Department of Transportation (WSDOT) has a long history of collecting and storing data that is electronically accessible and referenced against a Linear Referencing System (LRS). This data includes pavement surveys, contracts , capital projects, roadway configuration, maintenance activities, and more. This data has been successfully integrated from its many sources into the Washington State Pavement Management System (WSPMS). Data visualization is a key tool to utilize this vast amount of information when making pavement management decisions at the project, network and strategic levels. Commonly recommended data visualization techniques, such as bar charts, pie charts and GIS maps, lend themselves well to network and strategic analysis, but are difficult for efficient use at the project level. This paper provides an overview of the implementation and advantages of the Segment Viewer, the primary tool used for project level analysis in the web-based WSPMS software.

DATA VISUALIZATION AND PAVEMENT MANAGEMENT DECISION MAKING
Pavement management supports agency decisions at three different levels: strategic, network, and project. The types of decisions, range of assets considered, level of detail, and breadth of decisions differ across levels *(1)*. Moreover, decisions made at each level are synergistic; the decisions made at one level will directly affect results and decisions made at another level. Finally, the factors contributing to a decision may be numerous.

To consider all of these factors, a Pavement Management System needs to provide an integrated platform for decision analysis. The Washington State Department of Transportation (WSDOT) is very fortunate to have a long history of data integration using the Washington State Pavement Management System (WSPMS). This includes pavement surveys since 1969, contract information dating before the 1950s, capital project information since the mid-1980s, roadway configuration information, maintenance activities and more. Figure 1 is a copy of a mainframe computer printout from WSPMS in 1980, showing tabular data in conjunction with a graphical plot of historical pavement condition information. The fact that WSDOT maintained the same basic pavement management concepts over the last 40 years is the key reason that WSPMS has such a robust and complete database today. The data processing platforms have changed over the years (from mainframe to desktop to web-based), but the key foundation has been maintained and improved continuously *(2-5)*. As the amount of information has increased over the years, the ability to efficiently and effectively utilize it for decision making has become increasingly complicated.

Data visualization is a key tool to utilize this large amount of information. Due to the differences between pavement management decision levels, it is important to use the appropriate data visualization. Because strategic and network level decisions are made over groups of pavement assets, data visualization techniques related to statistics are useful to communicate: pie charts, bar charts, line charts, and histograms. Additionally, because of the spatial nature of pavement networks, a Geographic Information System (GIS) interface is also useful to communicate key attributes about these groups.

Figure 12. Washington State Department of Transportation project performance data.

FIGURE 1 Copy of WSPMS print out from 1980 (*2*).

However, GIS and singular chart visualization techniques are generally inefficient at communicating all of the detail useful at the project level. This is because the number of attributes that need to be compared quickly exceeds the visual space available. Therefore, pavement management systems most commonly resort to tabular or textual summaries. While visualizations may accompany such summaries (such as deterioration curves), they usually are not unified across the majority of data and not shown between adjacent segments. Indeed, this is how the WSPMS presented project level information until recently.

STRAIGHT LINE DIAGRAMS
Straight line diagrams, sometimes referred to as strip maps, have been used by many agencies as a method to visually unify attributes along a segment of roadway. Several variations of the straight line diagram have been in use for pavement information and pavement management (*6, 7*). While there are several variations, straight line diagrams generally display information scaled and aligned according to position in a straight-line representation of a route. Different pieces of data can then be stacked and visually compared, allowing the user to draw a straight line and see all of the data aligned by location. The advantage of such is layout is readily apparent, as it allows for visual comparison of the interaction of several attributes simultaneously.

Straight line diagrams are commonly static, usually presented in PDF format. The static straight line diagram has several weaknesses. For each weakness, a common compromise is used in response. However, when the straight line diagram is changed from a static to a dynamic interface, such as through interactive software, these weaknesses can be mitigated. Table 1 lists some of the weakness, static compromises, and solutions available in a dynamic medium (referred to as the dynamic solution).

TABLE 1 Straight Line Diagram Weakness, Static Compromise and Dynamic Solution

Weakness	Static Compromise	Dynamic Solution
Variation in types of data is limited by vertical space	• Only certain data is shown • Data is displayed on multiple "pages"	• Allow for the use of unlimited vertical space
Resolution of data along the route is dictated by scope and scale of the horizontal space	• Predefined segment scope (i.e. length) – all pages are scaled the same	• Allow the length, and therefore scale, of the segment to be changed arbitrarily by the user
Order of the data visualizations apply to certain analyses	• Order is ignored • Order is defined by most common use cases	• Allow the user to pick and order data relevant to the current analysis
Data not conforming to using distance for x-axis is difficult to deal with	• Omit data that is not conforming • Increase visual space to include (usually horizontally)	• Include alternate visualization styles at user discretion within the vertical space

For the WSPMS, a dynamic straight line diagram is the primary tool for project level analysis. It is called the Segment Viewer, includes all of the dynamic solutions listed in Table 1, and is part of larger PMS software called WebWSPMS.

STRUCTURE OF THE SEGMENT VIEWER
The vertical layout of the Segment Viewer is shown in Figure 2. A smaller portion at the top displays the route segment the user is currently viewing, called the Active Segment, along with additional controls. The remaining vertical space is used to present data about the Active Segment.

FIGURE 2 Basic structure of the Segment Viewer in WebWSPMS.

Selecting a Location

As opposed to strictly using pre-defined pavement management units, the WSPMS Segment Viewer allows the user to pick *any* section of Washington State Roadway, because pavement management decisions often require more factors than can reasonably be analyzed in pre-defined units. Moreover, data units often change over time, so less emphasis is placed on the limits the system may generate; putting more attention to proper analysis.

Data Components

Data in the Segment Viewer is divided into modular *Data Components*. Each Data Component corresponds to a specific piece of business logic. Data Components can be analyzed singularly and also in the context of other Data Components.

All Data Components share a common layout; a visual portion and an optional tabular portion. The tabular portion is similar across all data components. The visual portion follows a "visualization template", with templates reused across multiple Data Components. These templates are further explained later, but first it is helpful to review data integration and flow.

Data Integration

Data is integrated into the WSPMS from multiple sources within WSDOT using an Extract Transform Load (ETL) process. In other words, data is extracted from a source database, transformed for use within the WSPMS, and the product is saved for reuse throughout its expected life. Common transformations include normalizing column names or realigning route data temporally to match the alignment used by the WSPMS. Depending on the volatility of the data, the ETL process may happen daily, weekly, monthly or annually (most common).

Of key importance is not changing the segment granularity of the data during the ETL process, for several reasons. First, it allows the users to view the data in its most raw form directly from the WSPMS, which is useful to validate the originally ETL process. Second, when the data from several sources is transformed (summarized) into a more complex unit, the validity and exceptions to the transformation are easily compared since both the source and summarized data can be simultaneously displayed. Finally, it allows the data to be transformed in several ways without data loss between transformations.

Intelligent Segmentation

The data flow in the WSPMS is complex, and is not complete at the ETL process. There are two key interrelated steps when preparing data for pavement management; road network segmentation (the process of partitioning the road network into manageable units), and data aggregation (the summarization of data to adequately reflect the characteristics of the road segments) (*8*). In the context of the WSPMS, the combination of these activities is referred to as Intelligent Segmentation.

Of particular interest is how the WSPMS uses Intelligent Segmentation to manage condition information. The first step is to build the smallest condition units, called Survey Units, which are the core building blocks for pavement data interpretation. Survey Units have a target length of 0.1 miles and are homogenous with respect to surface type, surface age, and WSDOT region. Additionally, Survey Units have historical condition information summarized for all available years, which is used as inputs to location-specific pavement deterioration models (*3*). Second, an automated algorithm analyzes and aggregates Survey Units to create segments that are relatively uniform in condition, but allowed to be variable in length, called Preservation Units. The same algorithm is then applied, with different settings, over the Preservation Units to create longer Planning Units. WSDOT personnel can use these units, in conjunction with other information available in the WSPMS, to make project level decisions ranging from maintenance "hot spots" (Survey Units) to defining longer capital projects (Preservation and Planning Units).

Figure 3 shows the main data flow in the WSPMS, and many of the data segments created by Intelligent Segmentation. It is color coded by main source database, and arrows indicate ETL, segment definition, and data summarization processes. While Figure 3 is accurate

and particulars about WSPMS data flow can be elicited, the main point is to demonstrate the complicated data flow inherent in a pavement management system, reaffirming the need to leverage data visualizations.

FIGURE 3 Data Flow in the WSPMS
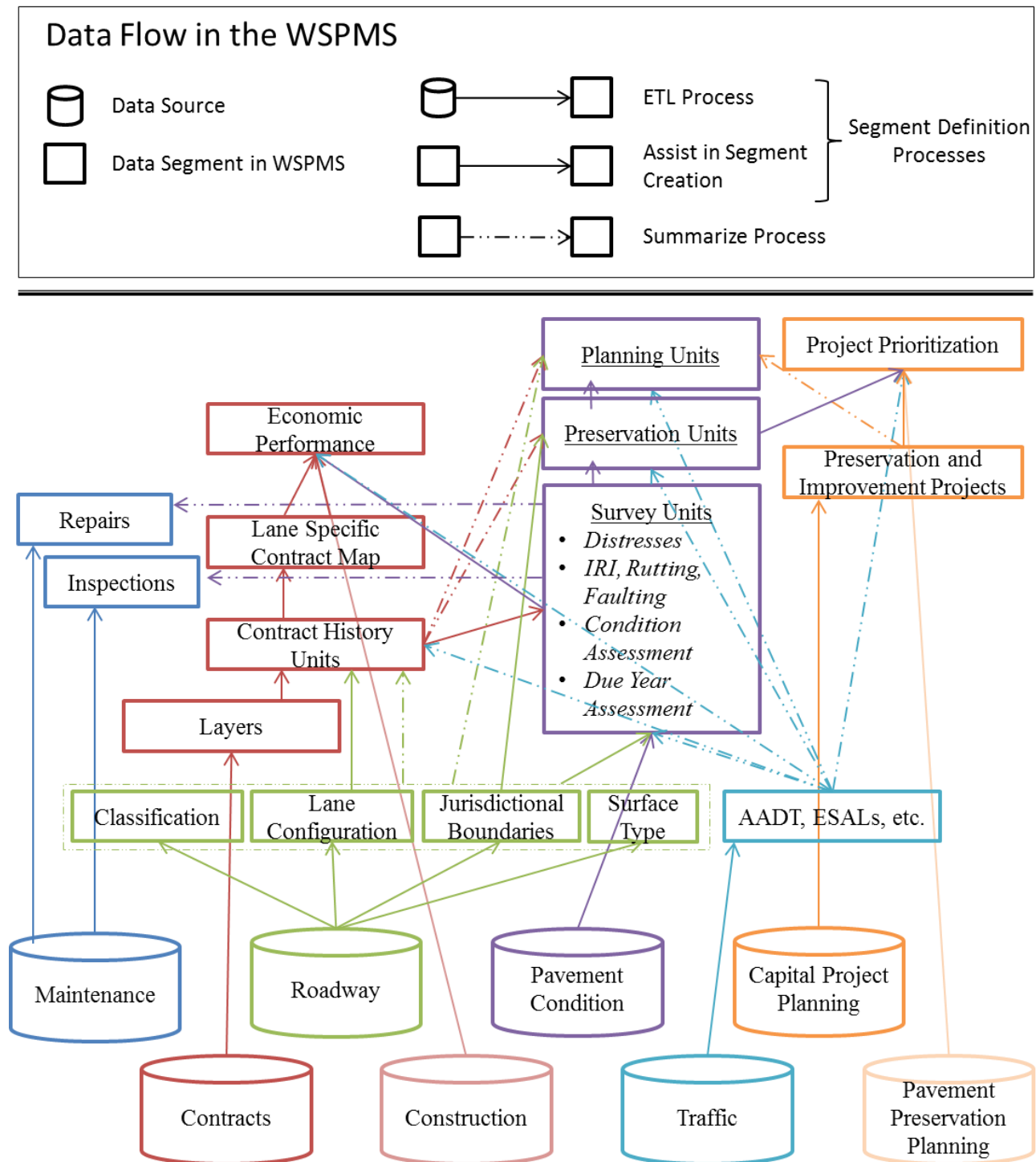
DATA VISUALIZATION TEMPLATES
With the vast amount of data available, it is essential for visualizations to be consistent and follow visualization patterns or templates. Within each template, it is important to consider the visual spaces to communicate data. A good list of visual spaces to consider are (assume that horizontal scale is already assigned to position along the route):
- Color
- Color Intensity
- Vertical Scale
- Text or symbolization
    In addition to these visualization spaces for communicating data, the interactive nature of the Segment Viewer opens it up for interactive space (mouse hover, mouse click, etc.). The following is a list of templates used in the Segment Viewer, serving as a brief reference, but may also make more sense after viewing the examples in the next section "Examples of the Segment Viewer."

Segment Template

The Segment template shows field values as colored segments. Examples include functional class, access type and jurisdictional boundaries. Each line is used to display a different field. Changes in color show changes in field value. Text shows the specific value. Mouse hover shows the attribute field, value, and extent (milepost limits) are displayed. Fields can be toggled on and off, allowing the user to display only commonly used fields or fields for the current analysis.

Entity Template

The Entity template displays entities as colored segments. Examples of entities include bridges, capital projects, and maintenance repairs. Vertical space is used to differentiate overlapping entities, and entities are grouped by whether they apply to the Increasing, Decreasing or Both directions. By default, color change is used to differentiate adjacent entities, but it is also often used to communicate the value of a specific attribute. Text is further used to communicate key attributes about the entity. On mouse hover, key attribute information is displayed. Finally, the mouse click is often used to sync the Active Segment to match the limits of the target entity.

Stepwise Line Graph Template

The Stepwise Line Graph presents numerical information graphed in a stepwise manner, with the length of the step corresponding to the granularity of data being displayed. Examples include distress information, IRI, rutting, condition indices, and Annual Average Daily Traffic (AADT). Color is used to indicate field name. Vertical space is used to show the range in values (i.e. y-axis scale). Users can select what to graph on the left and/or right y-axis, with sometimes several fields assigned as a group.

(Longitudinal) Cross Section

The Cross Section shows a longitudinal cross section of the roadway, based on contract information. Vertical space is used to scale depth (thickness), color is used for general material type, a mouse click shows a tabular version of all layers, and mouse hover shows more information (contract number, date, material type and thickness) over any layer.

Lane Configuration

The Lane Configuration shows number of lanes per direction (vertical space), surface material type (color), and lane type (symbols for HOV, thru-traffic and climbing). The median is also color coded as red or yellow for divided and undivided, respectively.

Contract Lane Map

The Contract Lane Map shows a plan view of the contract information for all lanes. It can be thought of as a hybrid between the Lane Configuration and Cross Section templates. Color is used to differentiate general material type, and is further gradated based on age (intense colors are newer and lighter colors older). Text can be optionally toggled to display age in years. Several interactions are available. A mouse-click shows all the layers at the lane and location targeted. Mouse hover shows the specific age, contract number and material type. Each contract can also be toggled on/off, allowing the user to see any point in the historical progression of construction and preservation of the roadway.

Non-Distance Templates

The templates previously explained were horizontally positioned and scaled relative to the Active Segment. Several pieces of data useful for project level analysis do not conform to this pattern. Examples include temporal data averaged over the Active Segment (Yearly Line Graph template) or the deterioration curves developed by the WSPMS (Curve template). While these Data Components do not strictly conform to the straight line diagram framework, their inclusion within the vertical visualization space has proven valuable for making project level decisions within WebWSPMS.

EXAMPLES OF THE SEGMENT VIEWER

The easiest way to understand how all of the visualizations interact is to view examples of the Segment Viewer. In the following three examples, the visualization template is shown italicized at left and legends explaining visualization choices are shown at right.

The first example, Figure 4, shows data often used to first analyze a section; Lane Configuration, Classification and Traffic Details. The Lane Configuration data component, shows the section is mainly asphalt, starts out as a simple two lane configuration and ends as a divided highway with 3 lanes in each direction. Next, the Classification data component shows the entire section is on the National Highway System (NHS), but the first portion is classified as Principal Arterial while the second portion is Freeway/Expressway. This coincides with the third data component, Traffic Details, which shows that the AADT starts at 10,000 and moves up toward 60,000 at the end of the section.
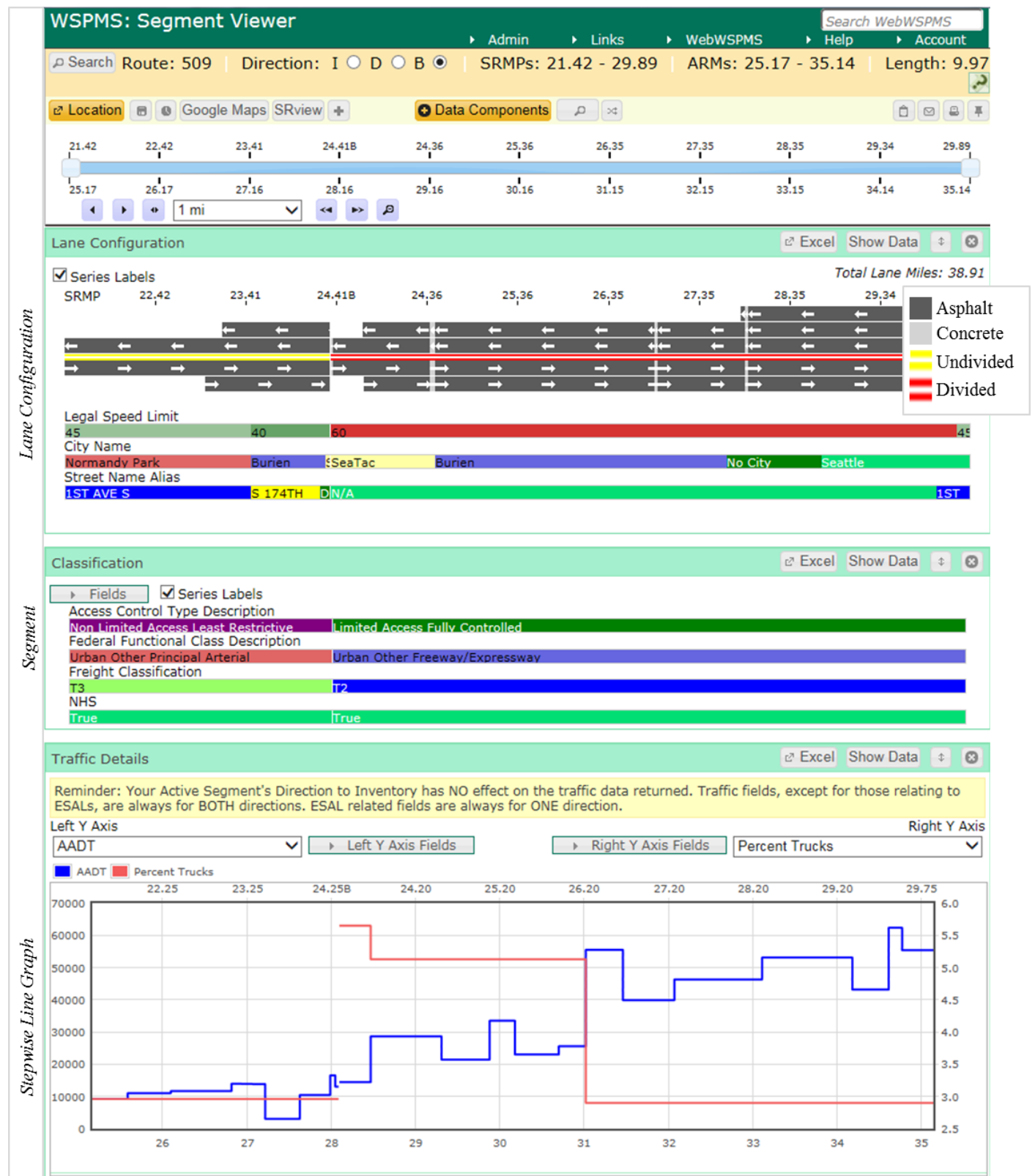
FIGURE 4 Example of the Segment Viewer showing Lane Configuration, Classification and Traffic.

        The second example, Figure 5, shows the relation between contract history, current condition, and pavement deterioration. Starting from the top, the Cross Section Data Component shows that the entire section was built in 1953, but the first portion was last resurfaced in 2006 while the second portion was last resurfaced in 2012.

        Next, the Condition Index Details displays the current condition for cracking (red) and rutting (light blue), showing that the portion resurfaced in 2006 has a rutting at approximately 0.7 inches (18mm), but not issues with cracking, while the portion resurfaced in 2012 is showing no issues. Third, the Preservation Unit data component shows that the first portion is contained in a Preservation Unit due for resurfacing in 2011 while the second section is contained in a Preservation Unit due for resurfacing in 2023. The final data component, Preservation Unit Curves, shows the deterioration curve for the first Preservation Unit.

FIGURE 5 Example of the Segment Viewer showing relation between contract history, current condition, and pavement deterioration.

The final example, Figure 6, shows several interactions between completed projects, planned projects and current condition. It also shows how WSDOT maximizes its preservation dollars by breaking up preservation projects into smaller, more surgical, sections.

FIGURE 6 Example of the Segment Viewer showing the interaction of completed projects, planned projects and current condition.

Each box (A through C) highlights information about the relation between completed projects, planned projects and pavement condition for the ten mile section. Box A shows a small portion that was recently resurfaced (five years prior), has good condition, and is therefore excluded from two preservation projects on either side. Boxes B and C are adjacent resurfacing projects for asphalt last resurfaced 17 to 19 years ago. Notice that the project in Box B just applies to the increasing direction of travel (there is a separate project for decreasing not shown), while Box C applies to both sides. Finally, notice that there are two distinct conditions present in Box B, the first part due in 2010 and the latter part due in 2016.

SEGMENT VIEWER AND OTHER SOFTWARE TOOLS

While the Segment Viewer is a powerful tool, it complements several other tools available within the WSPMS and at WSDOT. To enhance productivity, links to and from the Segment Viewer are provided when feasible. Figure 7 shows the Segment Viewer and related software tools available, along with showing the "one click" links that opens the software with a single click, at a specific location.

The software tools shown in Figure 7 are:

- Search Tool – Query different types of data segments based on their attributes.
- Preservation Planner – Add and view additional details about preservation projects being planned.
- Forecasting Tool – Tool used to forecast budget needs and analyze prioritization strategies based on performance measures *(9)*.
- Pavement Viewer – View the most recent images of the pavement inventory.
- Resurfacing and Design Reports – Current and historical pavement reports have been digitized and are automatically tagged on the WSDOT LRS.
- Bridge Information Viewer – An internal website that serves additional information for WSDOT bridges.
- SRview – An internal software application used to view biannual, starting in 2000, right-of-way imagery.
- ESRI ArcMap – Standard ESRI GIS software with integrated agency-specific layers and tools, called the WSDOT GIS Workbench. Layers are updated annually for Preservation and Survey Units.
- Contract Plans – A standard file share containing PDF contract plans and organized by contract number.
- Maintenance Tracking – An internal web-based application used by maintenance to track activities, including pavement inspections and repairs.
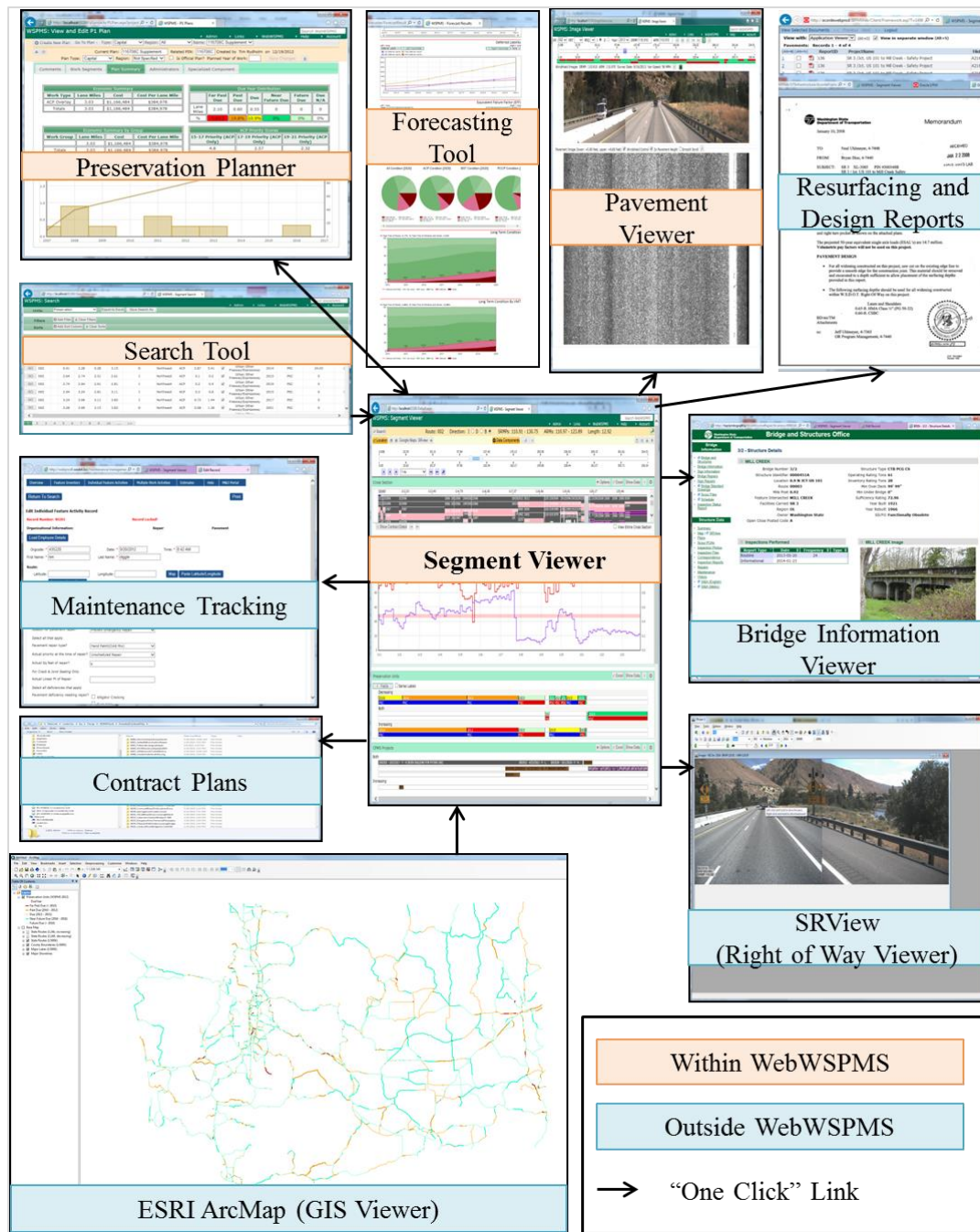
FIGURE 7 Relation of the Segment Viewer to some other software tools used at WSDOT.

SEGMENT VIEWER ON A MOBILE PLATFORM
A final advantage of the Segment Viewer makes use of its vertical layout, which is the use of the application on a tablet. WSDOT has successfully integrated and used WebWSPMS for in-field reviews. Moreover, the tablet version can automatically update the Active Segment location using GPS, and additionally track a straight line as the vehicle travels down the roadway. Comments and photos can also be uploaded in the field.

FIGURE 8 Screenshot from the Segment Viewer on an iPad Air (actual size), with mobile features annotated.

CONCLUSIONS

The commonly recommended data visualization techniques for pavement management, including pie charts, bar charts, and GIS maps, are generally more useful at the network and strategic decision making levels. The straight line diagram provides a solid model for analyzing project

level information, but has several weaknesses when used within a static interface. The dynamic straight line diagram format used in the Segment Viewer of WebWSPMS provides a solid framework for presenting data to make project level pavement management decisions, as shown in this brief overview. Such a powerful tool gives WSDOT confidence that the data is available and useable to make optimal project level decisions, increasing the cost effectiveness of its pavement management program.

DISCLAIMER
This paper contains the opinions and viewpoints of the authors alone, and does not constitute a policy or standard of the Washington State Department of Transportation.

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